MORTAR ANALYSIS

for the

PETWORTH LIBRARY

WASHINGTON, D.C.

Prepared for

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I. INTRODUCTION

This report is an analysis of mortar sampled from the Petworth Library in Northwest Washington D.C. John Milner Associates, Inc. extracted mortar samples from the site for analysis. Two representative samples were selected for analysis: a brick pointing mortar sample (MA01) and a limestone pointing mortar sample (MA02). The purpose of this analysis is to determine the physical composition of the mortars to inform the mix of a new mortar during the restoration of the building.

Mortar analysis is a visual and laboratory examination of cementitious building materials such as mortars, plasters, stuccos, and grouts for the purpose of determining composition and application techniques. The analysis is subjective, and primarily comparative in nature, and may be effectively used to assess the relationship between different parts of a structure or of a structure to similar sites elsewhere. The principal reason mortars are analyzed is to match historic mortars for repointing and reconstruction projects. It is critical that new mortars are physically compatible with adjacent materials and that the surface is aesthetically appropriate to the appearance of the significant historic period of the structure.

II. METHODOLOGY

Sampling

The mortar samples were extracted on April 29, 2008. The samples chosen for analysis are:

MA01- Brick Pointing Mortar

MA02- Limestone Pointing Mortar from the top of the northeast corner.

Analysis: Mortar

A freshly broken surface of the mortar sample was examined with a stereo-binocular microscope. Binder color and characteristics, proportion and characteristics of voids, and relationship between aggregate and binder were evaluated. The binder was matched to a color standard of the Munsell Color Chart.[1] A portion of the sample was ground in a marble mortar to disaggregate the material. The remainder of the sample was set aside for later use in evaluation of potential replication mixes.

The sample was then separated into three components: the acid-soluble fraction, the 'fines' (e.g. pigment, acid-insoluble cement residue, or silt-to clay-sized mineral grains), and the aggregate or sand. Separation was accomplished by wet-chemical techniques. The acid-soluble fraction was first removed by digestion with diluted hydrochloric acid. The fines were separated from the aggregate by washing and filtration, then dried and weighed. The weight of acid soluble material was calculated by the difference in weight of the sample before processing and its weight after processing.

[1] The Munsell System of Color Notation identifies color in terms of three attributes: hue, value, and chroma. Color standards are opaque pigmented films on coated paper mounted on charts for each hue.

Weight percentages of acid-soluble material, fines, and aggregate in the sample were calculated as an aid for determining an appropriate replication mortar type. The aggregate was examined microscopically to identify the component materials, as well as evaluate the color, opacity, and shape of the sand grains, and the presence and nature of impurities. The particle size distribution of the aggregate was determined by sieve analysis.

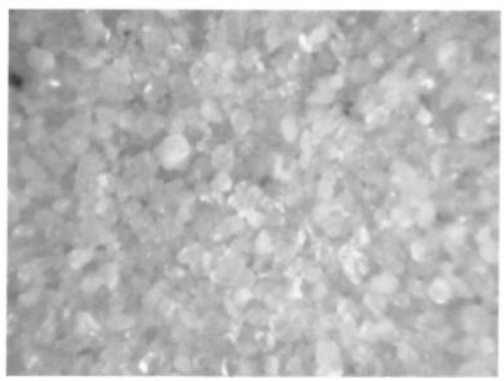
III. FINDINGS

Observations: Mortar

The mortar samples analyzed represent two different mortar mixes, one for brick and one for limestone. Both samples are hard cement-based mortars mixed with aggregate that is similar in color but not in composition. The limestone mortar aggregate is very fine while the brick mortar aggregate has larger grains. The limestone pointing mortar was mixed with an approximate ratio of 1:1 binder to aggregate by weight. Overall, the sample has a fine-grained appearance, is white in color, and features a tooled joint profile. The brick mortar was mixed with an approximate ratio of 1:3 binder to aggregate by weight. Overall, the sample is large-grained in appearance, is orange-brown in color, and has a ruled joint profile commonly used on colonial revival buildings. It was discovered during the sample extraction process that the limestone bed mortar is similar in appearance to the brick pointing mortar indicating the white limestone mortar was used exclusively as a pointing mortar to blend the stones together.

MA01

1. 

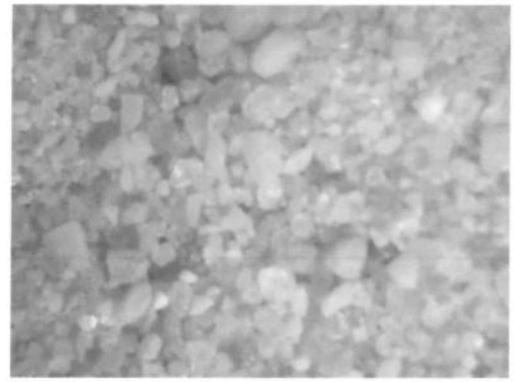
2. 

1.) Magnified image of mortar sample MA01 before acid digestion.
2.) Magnified image of the aggregate of the mortar after acid digestion.

The sample is taken from a 5/8" joint from limestone quoins. It does not break easily by hand and cleaves through the aggregate not the binder. The white binder is matte and smooth. The binder to aggregate ratio is heavy. Void volume is approximately 1% primarily in the form of oblong voids from entrapped air. Voids tend to be smaller than the medium aggregate. The color of the mortar is a grayish white (Munsell 10YR 9/2). Analysis indicates the ratio of binder to sand is approximately 1:1 by weight. The mortar is neutral with a pH of approximately 7.

The main portion of the sands are fairly uniform in composition and the overall color is a pale orange yellow (Munsell 10YR 8.5/1.5). Most of the grains are translucent but larger particles are opaque and vary in color from black, orange, to brick dust. The fines of the sample are light gray in color (Munsell 5Y 9/1).

MA02

1.  2. 

1.) Magnified image of mortar sample MA02 before acid digestion.
2.) Magnified image of the aggregate of the mortar after acid digestion.

The sample is taken from a 1/2" brick joint from the rear elevation. The sample does not break easily by hand and cleaves through the binder not the aggregate. The light brown binder is matte and textured. The binder to aggregate ratio is moderate. Void volume is approximately 15% primarily in the form of rounded, regular voids from entrapped air. Voids tend to be larger than the medium aggregate and smaller than the larger aggregate. The color of the mortar is a pale orange yellow (Munsell 10YR 8.5/3.5). Analysis indicates the ratio of binder to sand is approximately 1:3 by weight. The mortar is neutral with a pH of approximately 7.

The main portion of the aggregate is not uniform in composition and has an aggregate size very close to the ASTM standard for mortar. Most of the grains are opaque or translucent and vary in color from orange, to gray, to red. Overall, the color of the aggregate is a light orange brown (Munsell 10YR 7.5/4) The fines of the sample are pale orange yellow in color (Munsell 10YR 8.5/3.5).

IV. RECOMMENDATIONS

The chemical analysis indicates that both samples were fabricated with a cement-based binder and a light orange aggregate. The aggregate for the limestone pointing mortar was much finer than the brick aggregate most likely to match the grain of the stone. Cement/lime mortars were common in twentieth century architecture. For both the limestone and the brick, JMA recommends using a Type-N cement-lime mortar with a compression strength no stronger than 760 psi (as cured after one year) to minimize compression rate differences between the existing cement mortar that will remain in the wall, the new pointing mortar, and the masonry. The binder should be mixed with a well graded local aggregate that imparts a color to the mortar that is similar to what is existing in the wall. The aggregate should meet the ASTM Standard C144 for allowable particle size distribution in mortar aggregates as seen in the chart below:

Sieve Size	Percent Passing Maximum Allowable	Minimum Allowable	Median
10	100%	95%	98%
16	100%	70%	85%
35	75%	40%	58%
50	40%	10%	25%
100	25%	2%	14%
200	10%	0%	5%

Replication

JMA recommends a Type N cement-lime mortar using Portland Cement (gray or white depending on color-match), natural hydraulic lime, and matched aggregate. Natural hydraulic limes have become available in the US and should be considered for building conservation work. Hydraulic lime mortars are more vapor permeable than pure cement mortars, which aids water and salt removal within the masonry, and have better elasticity, allowing for building movement without cracking. Hydraulic limes do require treatment after placement to ensure proper curing, which is vital for frost resistance. The choice of a contractor with experience using hydraulic limes is the key to a successful project.

The replacement mortar must have good flexural strength, high permeability, and must exhibit a lower compressive strength than the existing masonry. Mock-ups of mortar mixes are required to determine the exact mortar recipe and products that will match the historic mortar. JMA will retain samples of the digested aggregate should you require a replication mix in the future.

Mortar Performance Characteristics

- Replacement mortar should match the physical properties of the existing mortar. Ideally the composition of the new mortar should duplicate that of the original. Current techniques can provide subjective data on properties of the mortar such as hardness, air content, and color; most also free the sand for matching. Actual values for weight percentages of sand and carbonate (through collection of carbon dioxide gas with the digestion of the mortar) can also be determined. Unfortunately, current analysis techniques such as the Cliver and Jedrzejewska methods cannot accurately determine the actual original mix; there are far too many variables.[2]
- Replacement mortar is intended to be sacrificial because it is easily replaced. Mortar should, therefore, be softer than the existing masonry, which is less durable than new stone because of weathering and other treatments.
- Replacement mortar must be more porous than the surrounding masonry it supports, thus allowing moisture that may enter a wall to pass through it to the exterior. Hard, dense mortars prevent this moisture movement, causing accelerated deterioration in the masonry unit rather than in the mortar joint.

[2] See Hanna Jedrzejewska, "Old mortars in Poland: a new method of investigation" in *Studies in Conservation*, V. 5, n. 4 (1960): 132-138.

Mortar Sample Preparation

- Prepare a range of samples to determine the appropriate materials and proportions for the new mortar. Small batches of sample mortars can be prepared off-site until a preliminary mix is developed.
- Final samples should be prepared on site at actual repair locations to determine application method and final tooling, and to establish a performance standard.
- **Final selection of the replacement mortar mix to be used is the responsibility of the owner or architect of record, and should be based on evaluation of the cause of failure of the existing mortar, and the condition and type of the masonry.**

Good Repointing Practice

- Repoint all open mortar joints in masonry walls. Leaving joints open will lead to moisture penetration and may, in turn, lead to material degradation of internal structural components.
- Friable, cracked, disintegrated joints must be cut back to sound mortar before repointing.
- Rake out existing deteriorated mortar to a depth of ¾-inch to 1-inch beyond the face of the joint.
- Install new mortar tooled to match the profile of the original mortar joints.
- Pack all voids in bedding mortar with new mortar, and then repointed to prevent face loading of the masonry and consequent spalling (face loading also occurs when pointing mortar is much harder than the bedding mortar).
- Do not install mortar during temperatures below 45°F or above 85°F.
- Properly cure new mortar to ensure that it does not dry out too quickly using a combination of protection and water misting as required. Failure to properly cure the mortar may lead to premature failure of the new work.

APPENDIX I: MORTAR ANALYSIS SUMMARY SHEETS

MORTAR ANALYSIS SUMMARY SHEET

Project Name: PetworthMA

Location:Limestone Quoin Pointing Mortar

Sample No.: MA01

Date: 05-09-08

Chemical Analysis

A. CALCULATIONS (weight in g.)

1. Container Weight:	159.55
2. Sample Weight	10.35
3. Filter Paper Weight	2.26
4. Container + Sand Weight:	163.02
5. Sand Weight:	3.47
6. Paper + Fines Weight:	3.74
7. Fines Weight:	1.48
8. Sand + Fines Weight:	4.95
9. Acid Soluble Weight	5.40
10. Weight Percent Sand	33.53%
11. Weight Percent Acid Soluble	52.17%
12. Weight Percent Fines	14.30%

B. PRE-TEST - Sample

Description: The sample is taken from a 5/8" joint from limestone quoins. The pointing mortar and the bedding mortar of the limestone blocks were not the same composition. The bedding mortar is similar to the mortar used for the brickwork. The processed sample only included the pointing mortar. The sample does not break easily by hand with cleavage through the aggregate not the binder. The white binder is matte and textured. The binder to aggregate ratio is heavy. Void volume is approximately 1% primarily in the form of oblong voids from entrapped air. Voids tend to be smaller than the medium aggregate.

Color Munsell Value: Munsell: 10YR 9/2 Color Name: White

	soft									hard
Relative Hardness:	1	2	3	4	5	6	7	8	9	**<u>10</u>**

C. POST-TEST - Sands

Color Munsell Value: Munsell: 10YR 8.5/1.5 Color Name: Pale Orange Yellow

Opacity: Opaque: 15% Translucent: 60% Transparent: 25%

Angularity: The particles are mostly rounded measuring R0.7/S0.9.

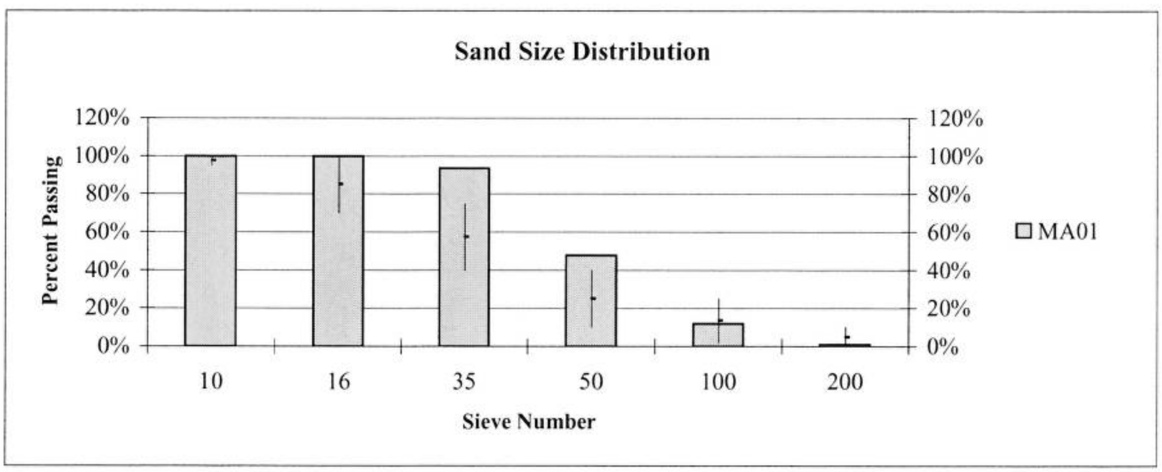
Composition: The main portion of the sands are fairly uniform in composition. Most of the grains are translucent or opaque ranging in color from red, to orange, to flecks of black. There are some brick dust particles but it does not appear that the brick dust was used for pigment or to impart any characteristics to the mortar.

Size:	Sieve No.	Weight	Percent Passing
	10	0.00 grams	100%
	16	0.00 grams	100%
	35	0.23 grams	93%
	50	1.58 grams	48%
	100	1.24 grams	12%
	200	0.38 grams	1%
	<200	0.03 grams	0%

D. POST-TEST - Fines

Color Munsell Value: Munsell: 5Y 9/1 Color Name: Light Gray

E. NOTES: There was high effervescence during acid digestion. The sample digested quickly with large bubbles but then it took a while to completely digest. The color of the acid solution changed to bright green during digestion indicating the presence of cement.



Note: Each vertical line represents the range allowable in a mortar sand for a given particle size as specified by ASTM C 144 Standard Specification for Aggregate for Masonry Mortar. Allowable percentages are different for natural and manufactured sands; this chart represents the absolute maximum and minimum of both aggregate types considered together. The bars represent the particle size distribution of the sample.

MORTAR ANALYSIS SUMMARY SHEET

Project Name: PETWORTHMA

Location:Brick Pointing Mortar

Sample No.: MA02

Date: 05-09-08

Chemical Analysis

A. CALCULATIONS (weight in g.)

1. Container Weight:	163.64
2. Sample Weight	21.08
3. Filter Paper Weight	2.24
4. Container + Sand Weight:	177.17
5. Sand Weight:	13.53
6. Paper + Fines Weight:	4.46
7. Fines Weight:	2.22
8. Sand + Fines Weight:	15.75
9. Acid Soluble Weight	5.33
10. Weight Percent Sand	64.18%
11. Weight Percent Acid Soluble	25.28%
12. Weight Percent Fines	10.53%

B. PRE-TEST - Sample
Description: The sample is taken from a 1/2" brick joint from the rear elevation. The sample does not break easily by hand with cleavage through the binder not the aggregate. The light brown binder is matte and textured. The binder to aggregate ratio is moderate. Void volume is approximately 15% primarily in the form of rounded, regular voids from entrapped air. Voids tend to be larger than the medium aggregate and smaller than the larger aggregate.

Color Munsell Value: Munsell: 10YR 8.5/3.5 Color Name: Pale Orange Yellow

Relative Hardness: soft 1 2 3 4 5 6 7 **8** 9 10 hard

C. POST-TEST - Sands

Color Munsell Value: Munsell: 10YR 7.5/4 Color Name: Light Orange Brown

Opacity: Opaque: 50% Translucent: 40% Transparent: 10%

Angularity: The particles are mostly rounded measuring R0.7/S0.9.

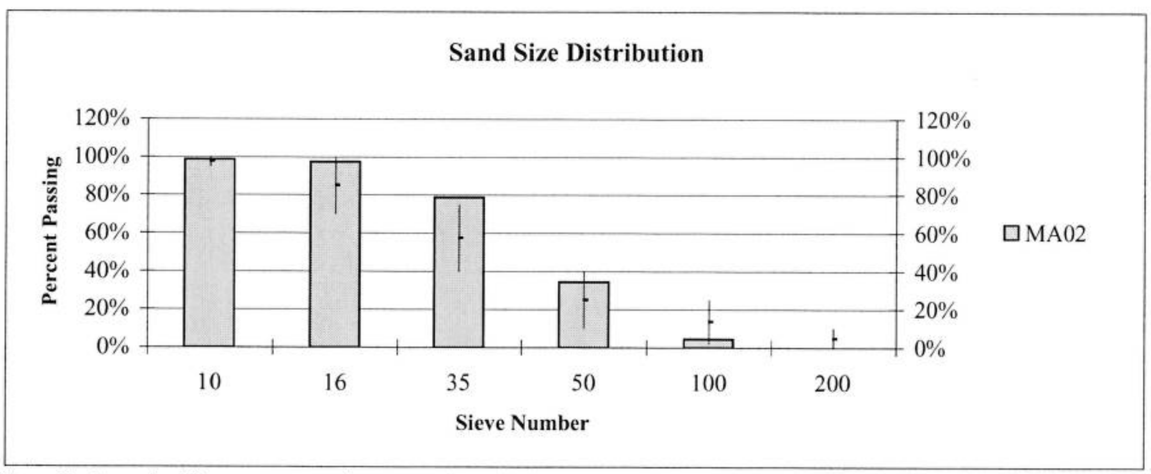
Composition: The main portion of the sands are fairly uniform in composition. Most of the grains are translucent and are light orange in color. Larger particles are opaque and vary in color from red, to gray, to brick dust.

Size:	Sieve No.	Weight	Percent Passing
	10	0.20 grams	99%
	16	0.18 grams	97%
	35	2.53 grams	79%
	50	6.04 grams	34%
	100	4.06 grams	5%
	200	0.62 grams	0%
	<200	0.01 grams	0%

D. POST-TEST - Fines

Color Munsell Value: 10YR 8.5/3.5 Color Name: Pale Orange Yellow

E. NOTES: There was high effervescence during acid digestion. The sample digested quickly with large bubbles but then it took a long time to completely digest.



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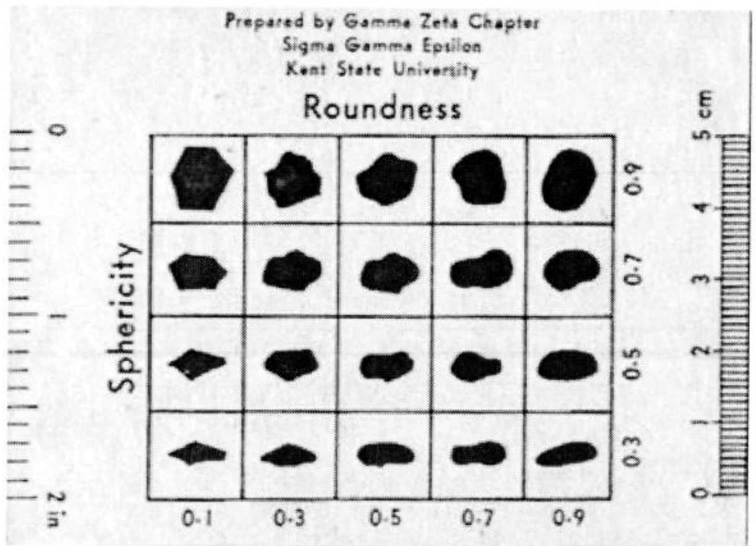
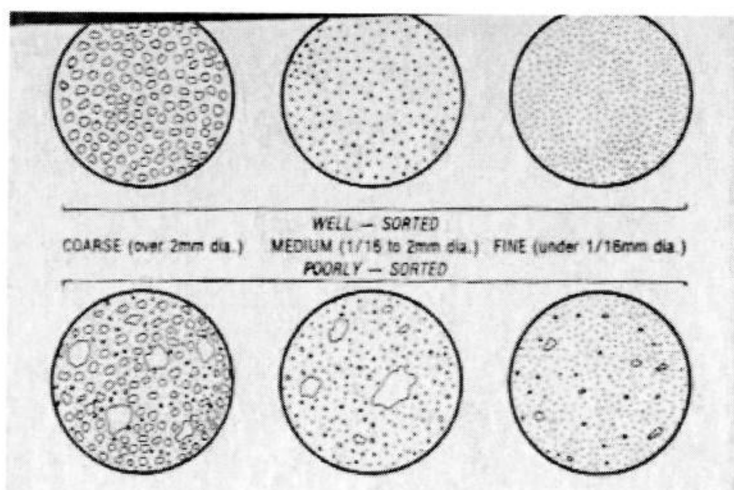


ROUNDNESS SCALE



GRAIN SIZE AND SORTING